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(54) **Method and apparatus for automatic delay compensation in space diversity radio transmissions**

(57) A method and apparatus is described for the automatic delay compensation in space diversity radio transmissions. The method comprises the steps of: a) receiving a first analog signal and a second analog signal, a possible delay being between the first and second signals; b) sampling said first and said second analog signals to obtain a first digital signal and a second digital signal, respectively; c) sending said digital signals to respective equalizers, and the steps of d) digitally delaying one of the first digital signal and the second digital signal by a period equal to an integral multiple of the sampling period, and e) recovering, at the equalization phase, the residual difference between the set delay and the actual one.
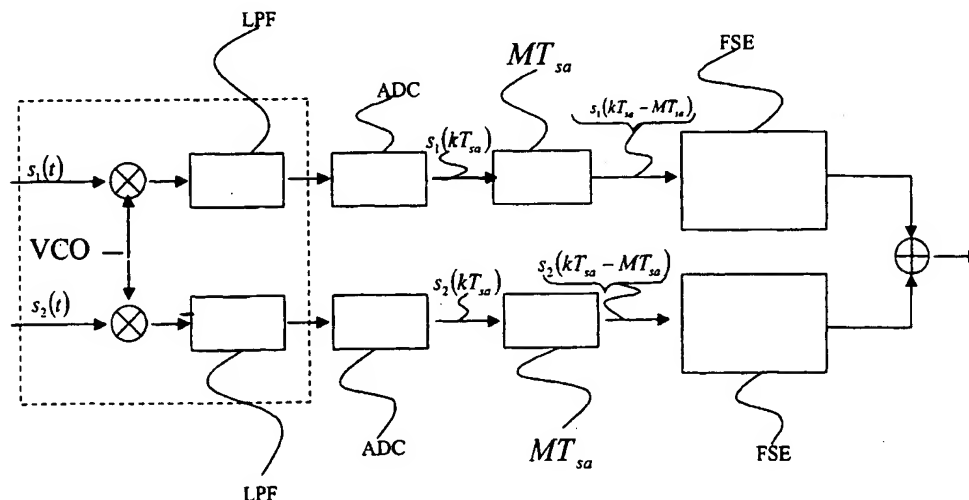
Fig. 2

Description

[0001]   The present invention relates to the field of radio transmissions and in particular it relates to the space diversity systems. Still more in particular, it concerns a method and an apparatus for compensating, in an automatic and digital manner, the relative delay between the two (or more) signals received simultaneously.

[0002]   In a high-capacity radio transmission system the channel distorting effects are well known, mainly due to the multipath phenomenon: the receiving antenna can in fact receive, along with the wished signal, a delayed replica thereof, caused by the reflection of the transmitted signal from tropospheric layers having unusual physical character-istics or by the reflection from orographic obstacles. Such a corruptive effect is known in the leterature as selective fading. Under exceptionally unfavourable conditions the fading can even result in the radio system to be out-of-order, since the received signal becomes no longer intelligible.

[0003]   A first, possible and widely used in practice, countermeasure is represented by the adaption of an adaptive equalizer inside the demodulation apparatus. This solution, sometimes, may be not enough in the case of radio spans extraordinarily long or installed under exceptionally unfavourable geographic conditions.

[0004]   Another possible alternative consists in providing a space diversity system, based upon the transmission of a signal which is received simultaneously by two or more different antennas (hereafter, two antennas will be considered by way of a non limiting example). The operating philosophy of the space diversity system consists exactly in sending the same information to the receiver by means of two distinct signals (one will be called "main" and the other will be called "diversity"). The effectiveness of this method depends on the fact that if the antennas are sufficiently spaced out in height, the received signals can be deemed uncorrelated and hence it is extremely unlikely that both signals exhibit the same quality at the same instant.

[0005]   Two main methods for processing the pairs of received signals are known: switching and combination. Switch-ing is based on the selection, theoretically at every instant, of the best of the two signals through a suitable criterion (typically the BER or Bit Error Rate).

[0006]   An approach deemed more effective consists in processing the two diversity signals by properly combining them. The procedure often used in this case is the one illustrated in Fig. 1, in which the two signals, main and diversity, suitably sampled, are the inputs of two FSEs (Fractionally Spaced Equalizers) whose output is summed and represents the result of the combination.

[0007]   However, because of the different positioning height of the two antennas at the receiving tower, of the different length of the waveguides or in any case of the various connection cables, the main and diversity signals may reach the samplers of Fig. 1 delayed one to each other. In order to realize the combination in an effective manner it is necessary to compensate for such a delay. Generally, once the delay has been measured by means of proper instruments, it is compensated during the installation of the radio link by adding to one of the two signals a cable length such that the transit time is equal to the delay to be compensated of by means of proper analog delay cells suitably adjustable.

[0008]   Unfortunately, this solution has the drawback of entailing a high cost and of the need to carry out the calibration on the field (thus requiring long times to reach the antennas).

[0009]   The main object of the present invention is therefore to provide a method and an apparatus for compensating the relative delay between the two paths.

[0010]   This and further objects are achieved by a method comprising the steps set forth in claim 1 and an apparatus having the characteristics set forth in claim 4. The respective dependent claims define additional characteristics of the invention.

[0011]   In accordance with the present invention, the compensation is carried out in a digital and automatic manner.

[0012]   The invention will become clear in view of the following detailed description, given by way of a mere non limiting example to be read with reference to the appended drawing figures wherein:

- Fig. 1 is a basic diagram of a baseband combiner according to the prior art, parts related to the base-band down-conversion and to the analog signal sampling by means of analog to digital converters being indicated.
- Fig. 2 is a basic diagram of a base-band combiner with the two delayed paths; and
- Fig. 3 schematically shows the compensation apparatus according to the present invention.

[0013]   As said above, an apparatus according to the prior art is illustrated in Fig. 1, which apparatus processes the two signals and combines them suitably. The two signals, main and diversity ($S_1(t)$, $S_2(t)$) are entered into a voltage controlled oscillator (VCO) and are low-pass filtered (LPF); each of them is then passed through an analog to digital converter (ADC) for sampling and through a fractionally spaced equalizer (FSE). The outputs from the equalizers are then summed and substantially represent the result of the combination. The dashed-line square in Fig. 1 (and similarly in Fig. 2) represents the analog portion of the device).

[0014]   In order to implement the combination in an effective manner it is, on the other hand, necessary to compensate for the delay with which the signals reach the samplers. Consider for instance two signals entering the demodulator

and coming from the main antenna (signal 1) and from the diversity antenna (signal 2), respectively. If signal 1 is τ seconds late after signal 2, in order to be able to realize the combination in an effective manner, it is necessary to delay, in principle, the signal 2 by τ seconds.

[0015]   Let $s_1(t)$ and $s_2(t)$ be the two analog signals at the input of the demodulator, namely:

$$s_1(t) = \sum_{k=-\infty}^{+\infty} a_k g_1(t - kT - \tau) \quad \text{and} \quad s_2(t) = \sum_{k=-\infty}^{+\infty} a_k g_2(t - kT)$$

a_k being the transmitted symbol, T being the signalling interval and $g_1(t)$ and $g_2(t)$ being the pulse responses comprising the transmit and receive filtering chain and the pulse response of the channel as "viewed" from the main antenna and from the diversity antenna, respectively.

[0016]   Let $s_1(KT_{sa})$ and $s_2(KT_{sa})$ the main and diversity signals sampled with period T_{sa} by the analog to digital converter (ADC). So it is possible to digitally delay the signal 2 by a period equal to integer multiples of T_{sa}, namely such that $M \cdot T_{sa}$, M being an integer, be as much as possible an approximation of the delay τ (see Fig. 2). The difference $|MT_{sa} - \tau|$, however being still less than $T_{sa}/2$, will be recovered by the equalizers (FSE) by virtue of their interpolation capabilities (see, e.g., the publication "Data Communications Principles" by R. Gitlin, J. Hayes, S. Weinstein, ed. Plenum Press, New York, 1992, paragraph 7.4.4, pages 493 to 495).

[0017]   The algorithm which is the subject-matter of the present invention seeks to determine, in an automatic manner, the value of M (without knowing a priori if signal 1 is late after signal 2 or *vice versa*), by operating in the way that will be described below with reference to Fig. 3.

[0018]   First, several delayed replicas of both signal 1 and of signal 2, are obtained, namely signals of the following type are obtained:

$$r_{1j}(kT_{sa}) = s_1(kT_{sa} - jT_{sa}) \text{ and } r_{2i}(kT_{sa}) = s_2(kT_{sa} - iT_{sa})$$

with $0 \le j \le N_1$ and $0 \le i \le N_2$, $N_1 T_{sa}$ being the maximum assumable delay of signal 1 with respect to signal 2 and, similarly, $N_2 T_{sa}$ being the maximum assumable delay of signal 2 with respect to signal 1.

[0019]   Note that in general it may happen that $N_1 \ne N_2$.

[0020]   In Fig. 3, only by way of example and not of limitation, it has been set $N_1 = 0$ and $N_2 = 4$ for simplicity.

[0021]   Thereafter the various cross-correlations are calculated

$$xc_{1j} = E\left\{s_1(kT_{sa} - \tau - jT_{sa}) \cdot s_2^*(kT_{sa})\right\} =$$
$$= E\left\{\sum_m \sum_n a_n a_m{}^* g_2{}^*(kT_{sa} - mT)g_1(kT_{sa} - nT - \tau - jT_{sa})\right\} \quad \text{with } 0 \le j \le N_1 \quad (1)$$

$$xc_{2i} = E\left\{s_1^*(kT_{sa} - \tau) \cdot s_2(kT_{sa} - iT_{sa})\right\} =$$
$$= E\left\{\sum_m \sum_n a_m a_n{}^* g_1^*(kT_{sa} - nT - \tau)g_2(kT_{sa} - mT - iT_{sa})\right\} \quad \text{with } 0 \le i \le N_2 \quad (2)$$

where * denotes the complex conjugate operation and $E\{\cdot\}$ the time-average operation.

[0022]   Then, the maximum value between xc_{1j} and xc_{2i} is determined as i and j *are* varied, normally will be

$$M = \max_{i,j}\left(\left|xc_{1j}\right|^p, \left|xc_{2i}\right|^p\right).$$

p being a positive integer higher than 0.

[0023]   In fact, considering that $g_1(t) \cong g_2(t)$ (indeed the installation occurs in the absence-of-fading condition, and

hence the channel which is viewed from the two antennas is very similar) and that the autocorrelation of $g_1(t)$ or $g_2(t)$ is at its maximum for t = 0 (about the way the filterings are normally constituted), it is clear that in the case in question, the modulus of the cross-correlation best approximating

$$E\{s_1(t)s_2^*(t-\tau)\}$$

will be a maximum.

[0024]   Either signal 1 or signal 2 of MT_{sa} is delayed, depending on whether the correlation is of type xc_{1j} or of type xc_{2i}.

[0025]   Clearly, the cross-correlations xc are complex numbers; in order to calculate the maximum thereof, their modulus raised to "p", should be calculated, p being a positive integer, usually equal to 2 for convenience.

[0026]   In Fig. 3 a possible circuit implementation is shown wherein the switching circuit (SWTC), according to the information which are received from the computation of the maximum, selects the proper delay to be inserted (in this case on path 2); "corr" denotes the computation of the cross-correlation, as indicated above.

[0027]   Although in Fig. 3 it has been set $N_1=0$ and $N_2=4$ for simplicity, any other combination of N_1 and N_2 is possible and Fig. 3 would assume a correspondingly different aspect.

[0028]   In practice, however, the device according to the invention would operate assuming first $j=0$ and making i change from 1 to N_2, afterwards assuming i = 0 and making j change from 1 to N_1 until the value of M is found (as it is apparent from (1) and (2)).

[0029]   It is apparent that the present invention can be embodied in the form of a circuit or a computer software program. The scope of the present patent application therefore covers also such a computer software program and to the computer into which such program is stored and runs. It is also apparent that several modifications and adaptations can be imparted to the present invention without departing from the scope defined by the following claims which are intended to form an integral part of the present description.

Claims

1.   Method of compensation for the possible delay between two or more radio transmission paths in space diversity radio transmissions, said method comprising the steps of:

   -   receiving a first analog signal $(s_1(t))$,
   -   receiving at least a further analog signal $(s_2(t))$;
   -   sampling (ADC) said first and said at least a further analog signals $(s_1(t), s_2(t))$, to obtain, a first digital signal $(s_1(KT_{sa}))$ and at least a further digital signal $(s_2(KT_{sa}))$, respectively, T_{sa} being the sampling period, a possible delay (τ) being present between the first and the at least a further digital signals; and
   -   sending said digital signals $(s_1(kT_{sa}), s_2(kT_{sa}))$ to respective equalizers (FSE);

   said method being **characterized by** the step of

   -   delaying (MT_{sa}) in a digital manner one of said first digital signal $(s_1(KT_{sa}))$ and said at least a further digital signal $(s_2(KT_{sa}))$ by a period equal to an integer multiple (M) of the sampling period (T_{sa}), and possibly by the step of
   -   recovering, at the equalization step, the difference between the imposed delay (MT_{sa}) and the real one (τ).

2.   Method according to claim 1, **characterized in that** the delaying step comprises the step of calculating in an automatic manner the value of the integer multiple (M), wherein said step of calculating the integer multiple (M) in turn comprises the steps of:

   -   realizing delayed replicas $(r_{1j}(kT_{sa}), r_{2i}(kT_{sa}))$ $r_{1j}(kT_{sa}) = s_1(kT_{sa} - jT_{sa})$ and $r_{2i}(kT_{sa}) = s_2(kT_{sa} - iT_{sa})$ of said first $(s_1(kT_{sa}))$ and said at least a further $(s_2(kT_{sa}))$ digital signals, with $0 \le j \le N_1$ and $0 \le i \le N_2$, $N_1 T_{sa}$ being the maximum assumable delay of the first signal with respect to the at least a further signal and, similarly, $N_2 T_{sa}$ the maximum assumable delay of the at least a further signal with respect to the first signal:
   -   calculating the cross-correlations (xc_{1j}, xc_{2i})

$$xc_{1j} = E\left\{\sum_m \sum_n a_n a_m * g_2 * (kT_{sa} - mT)g_1(kT_{sa} - nT - \tau - jT_{sa})\right\} \qquad \text{with } 0 \leq j \leq N_1,$$

$$xc_{2i} = E\left\{\sum_m \sum_n a_m a_n * g_1^*(kT_{sa} - nT - \tau)g_2(kT_{sa} - mT - iT_{sa})\right\} \qquad \text{with } 0 \leq i \leq N_2,$$

between the various delayed replicated signals ($r_1(kT_{sa})$, $r_2(kT_{sa})$), where * denotes the complex conjugate operation and $E\{\cdot\}$ the time average operation;
- deriving the maximum value of said cross-correlations (xc_{1j}, xc_{2i}) as i and j are varied

$$M = \max_{i,i}\left(|xc_{1j}|^p, |xc_{2i}|^p\right)$$

said maximum value corresponding to the value of the integer multiple (M).

3. Method according to claim 2, **characterized by** comprising the further step of selecting (SWTC) the proper delayed replica ($r_1(k_{sa})$, $r_2(kT_{sa})$), to be sent to said equalizers as a function of the information related to the maximum of the calculated cross-correlations.

4. Apparatus for compensating the delay between two or more radio transmission lines in space diversity radio transmissions, said apparatus comprising:

   - means for receiving a first analog signal ($s_1(t)$);
   - means for receiving at least a further analog signal ($s_2(t)$);
   - means (ADC) for sampling the first and the at least a further analog signal ($s_1(t), s_2(t)$) to obtain, a first digital signal ($s_1(kT_{sa})$) and at least a further digital signal ($s_2(kT_{sa})$), respectively, T_{sa} being the sampling period, a possible delay (τ) being present between the first and the at least a further digital signals; and
   - equalizers (FSE) receiving said digital signals ($s_1(kT_{sa}), s_2(kT_{sa})$) at the input;

   said apparatus being **characterized by** comprising

   - means (MT_{sa}) for delaying in a digital manner one of said first digital signal ($s_1(kT_{sa})$) and said at least a further digital signal ($s_2(kT_{sa})$) by a period equal to an integer multiple (M) of the sampling period (T_{sa}), and equalizer means capable of restoring the difference between the imposed delay (MT_{sa}) and the effective one (τ).

5. Apparatus according to claim 4, **characterized in that** said delay means comprise means for calculating in an automatic manner the value of the integer multiple (M), wherein said automatic calculation means in turn comprise

   - means for realizing delayed replicas ($r_1(kT_{sa})$, $r_2(kT_{sa})$) $r_1(kT_{sa}) = s_1(kT_{sa} - jT_{sa})$ and $r_2(kT_{sa}) = s_2(kT_{sa} - iT_{sa})$ of said first ($s_1(kT_{sa})$) and said at least a further ($s_2(kT_{sa})$) digital signals, with $0 \leq j \leq N_1$ and $0 \leq i \leq N_2$, $N_1 T_{sa}$ being the maximum assumable delay of the first signal with respect to at least a further signal and, analogously, $N_2 T_{sa}$ the maximum assumable delay of the at least a further signal with respect to the first signal;
   - means for calculating the cross-correlations (xc_{1j}, xc_{2i})

$$xc_{1j} = E\left\{\sum_m \sum_n a_n a_m * g_2 * (kT_{sa} - mT)g_1(kT_{sa} - nT - \tau - jT_{sa})\right\} \qquad \text{with } 0 \leq j \leq N_1,$$

$$xc_{2i} = E\left\{\sum_m \sum_n a_m a_n * g_1^*(kT_{sa} - nT - \tau)g_2(kT_{sa} - mT - iT_{sa})\right\} \qquad \text{with } 0 \leq i \leq N_2$$

between the various delayed replicated signals ($r_{1j}(kT_{sa})$, $r_{2j}(kT_{sa})$), where with * denotes the complex conjugate operation and $E\{\cdot\}$ the time average operation; and

- means for deriving the maximum value of said cross-correlations (xc_{1j}, xc_{2i}) as i and j vary

$$M = \max_{i,j}\left(\left|xc_{1j}\right|^{P}, \left|xc_{2i}\right|^{P}\right),$$

said maximum value corresponding to the value of the integer multiple (M).

6. Apparatus according to claim 5, **characterized by** further comprising switching means (SWTC) for selecting the proper delayed replica ($r_{1j}(kT_{sa})$, $r_{2j}(kT_{sa})$) to be sent to said equalizer means as a function of information related to the maximum of the cross-correlations calculated.

7. Computer program comprising computer program code means adapted to perform all the steps of claims 1 to 3 when said program is run on a computer.
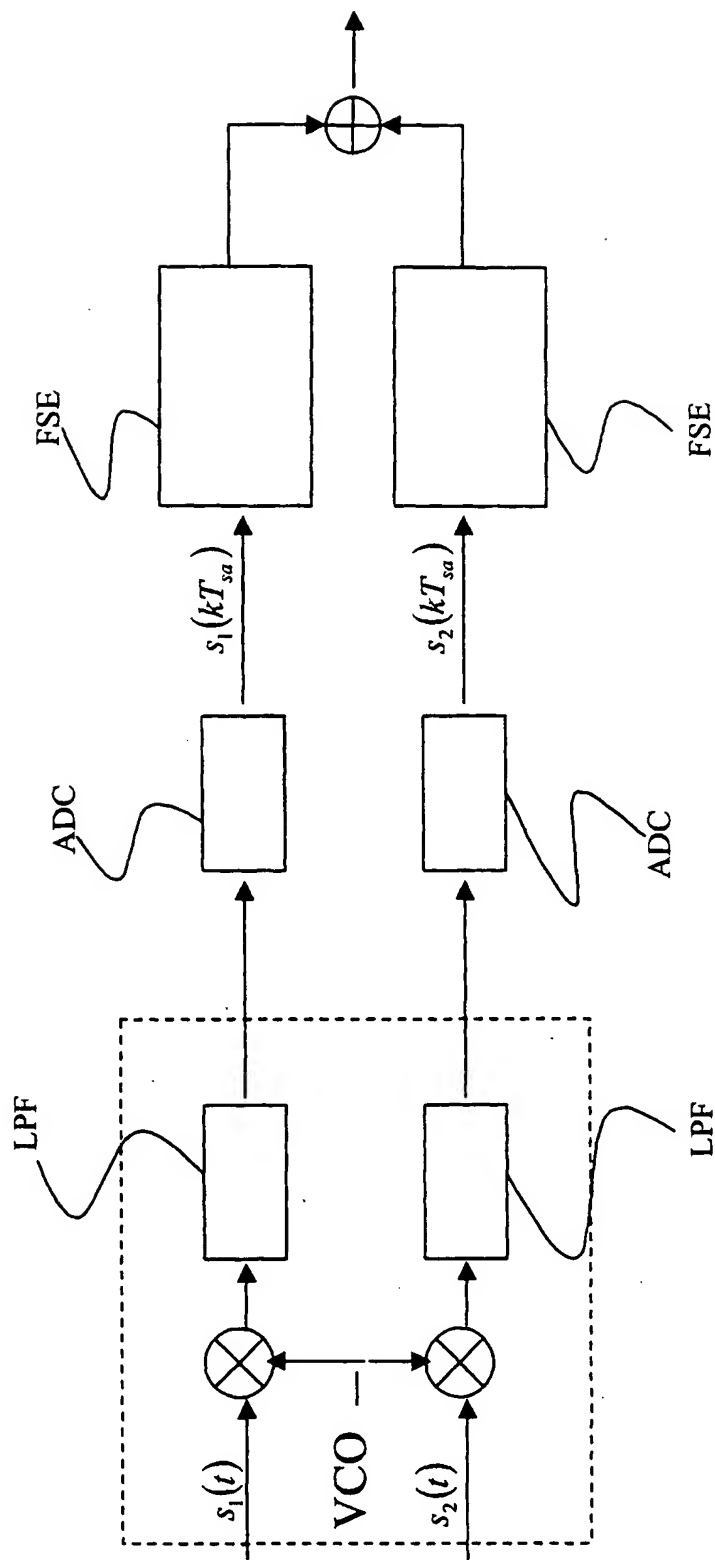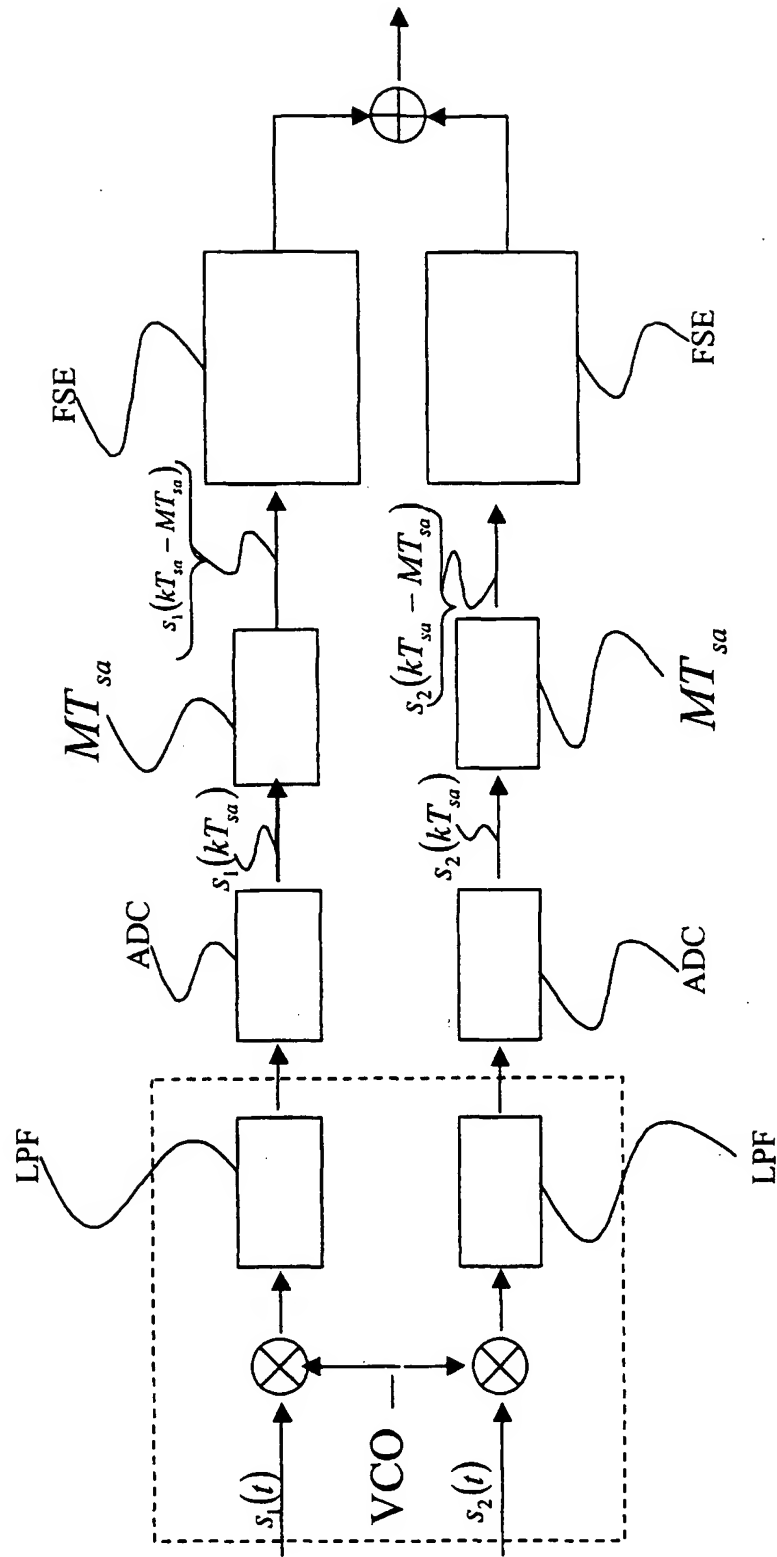
8. Computer-readable medium having a program recorded thereon, said computer-readable medium comprising computer program code means adapted to perform all the steps of claims 1 to 3 when said program is run on a computer.
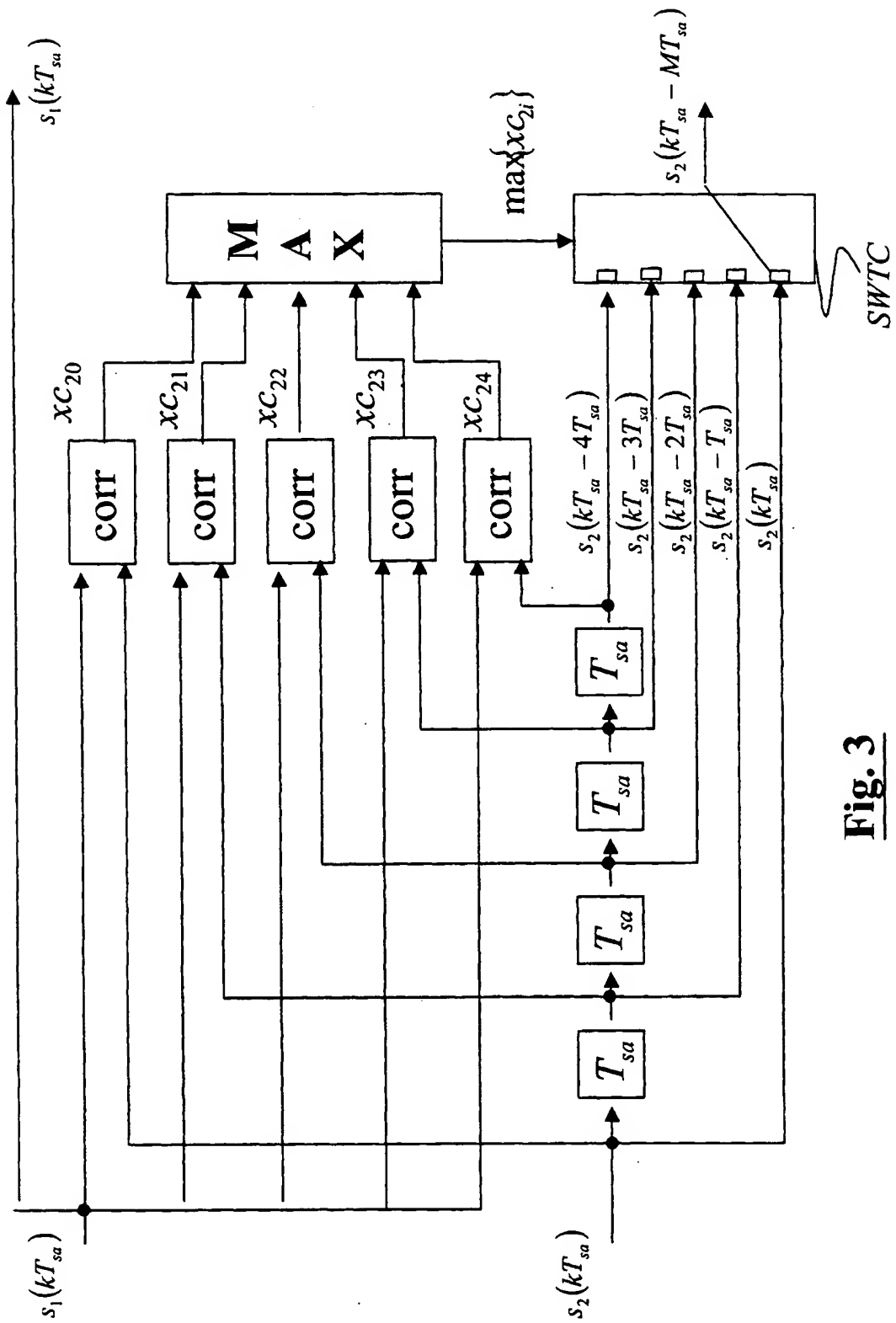
Fig. 1

Fig. 2

Fig. 3